The resulting elements and their probable errors are—

Perihelion Passage, March $17^{d}\cdot001823 \pm 0^{d}\cdot000511$ G.M.T. or
March 17 0^{h} 02^{m} $37^{s}\cdot5 \pm 35^{s}\cdot5$ G.M.T.

$$\left.\begin{aligned} \Omega' &= 273^{\circ}\ 31'\ 26''\cdot29 \pm 6''\cdot13 \\ \pi' &= 237\ \ 14\ \ 06\cdot81 \pm 6\cdot13 \\ \omega' &= 323\ \ 42\ \ 40\cdot52 \pm 8\cdot67 \\ \iota' &= \ \ 37\ \ 45\ \ 59\cdot07 \pm 2\cdot83 \end{aligned}\right\} \text{Equator and Equinox of } 1888\cdot0.$$

$$\log q = 9\cdot8443367 \pm 0\cdot0000042$$
$$e = 0\cdot9958467 \pm 0\cdot0000438$$

or if referred to the ecliptic—

$$\left.\begin{aligned} \Omega &= 245^{\circ}\ 22'\ 56''\cdot0 \\ \pi &= 245\ \ 18\ \ 26\cdot9 \\ \omega &= 359\ \ 55\ \ 30\cdot9 \\ \iota &= \ \ 42\ \ 15\ \ 10\cdot0 \end{aligned}\right\} \text{Equinox } 1888\cdot0.$$

The period of revolution is $2182\cdot3 \pm 34\cdot6$ years, and the probable error of an element of normal place is $2''\cdot20$ on a great circle; which shows that the mode of determining normals is satisfactory. All the equations of condition were considered of the same weight.

The large inclination of the orbit of this comet places it beyond the action of the outer and larger planets; but it will be seen that the perihelion and node are almost coincident; at the time of perihelion, too, the comet is only $0\cdot027$ (in parts of the Earth's mean distance from the Sun) from the orbit of *Venus*; so that if that planet had been in conjunction with the comet when in perihelion, it would have exercised on the comet a force $\frac{1}{270}$ of the solar attraction. It seems possible, therefore, that we owe this member of our system and the present form of its orbit to the action of *Venus* at some remote date.

On the Value of a Scale of Density on a Photograph.
By Captain W. de W. Abney, C.B., R.E., F.R.S.

In the last three eclipse expeditions which have been sent out from England under the auspices of the Royal Society it has fallen to my lot to have a good deal to say on the photographic arrangements, and at the last expedition to Grenada I devised a means of visually ascertaining the comparative brightness of the corona at different points in its surface. It struck me at the time how valuable it would be if, instead of eye measurements, the photographed image could be utilised, as then there would

be a record which could be measured at leisure, and no liability of flurry, which during an eclipse must to some extent always be present. What I propose to show is, how this can be done in a most simple manner by a small preliminary arrangement. I will trace the steps which gradually led me to devise the method I have adopted. There are extant a few instruments for measuring the sensitiveness of photographic plates which go by the name of Spurge's Sensitometer, and one of these is in my hands. It was nearly the first made by the inventor, and is an admirable instrument in many ways. The instrument consists of a series of small chambers side by side, with orifices pierced in the top of each, of different sizes. If the area of one orifice is designated by 1, then the area of the next to it is $2^{\frac{1}{3}}$, of the next $2^{\frac{2}{3}}$, and of the next 2, and so on. Every chamber has an orifice of twice the area of the third previous one. A plate exposed behind such a series of chambers for a fixed time to a uniformly illuminated surface evidently has at different parts of it different intensities of light acting on it, and on development will give a series of densities of deposit, varying according to the intensities of the light acting on it. What the law of density of deposit compared with intensity of light acting is I will not give here, though I have ascertained from experiment and calculation that a definite law does appear to exist, and one which will prove of value, I am led to believe. For my present purpose, however, it will be sufficient to point out the manner in which this density can be accurately measured. For this purpose all that is necessary is to place the negative in front of a condenser with a steady light some little way in rear of it, and form a magnified image of the plate on a white screen.

By placing a mirror a little to one side of such a light a patch of white light can be superposed over this image; and if a rod be placed in the beam of light coming through one of

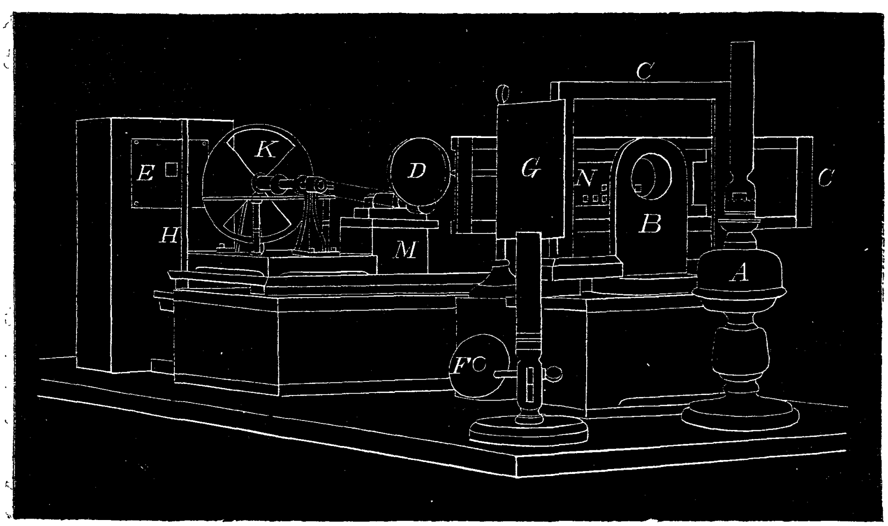


Fig. 1.

these small squares of deposit on the plate, two shadows will be thrown on the screen, one by the direct beam coming through the negative, and the other from the reflected light. The shadows will be illuminated in the ordinary Rumford photometer. A (Fig. 1) is the lamp, B the condenser, C the frame for holding the negative, D the lens which throws the magnified image, N the negative, E the receiving screen, H the rod casting the shadows, G the mirror above alluded to, K the sectors which are to be immediately described. The image of the square of deposit is bordered by a black mark to prevent the eye wandering, and the lens which throws the image is stopped down so as to make the light coming through a part of the plate on which there is no deposit rather less than one-half as bright as the reflected beam. The question is now how the shadows can be equalised. This I find most readily done by reducing the light of the reflected beam by means of rotating sectors which can be opened and closed during rotation. The following description is taken from one of my Cantor lectures recently delivered before the Society of Arts :—

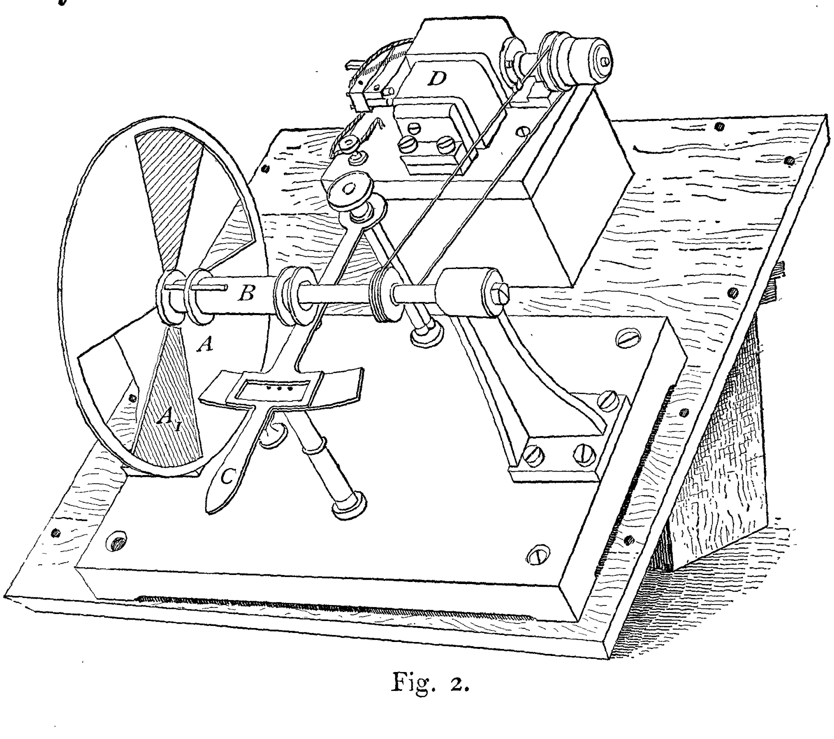


Fig. 2.

The annexed figure (Fig. 2), is a bird's-eye view of the instrument. A A are two sectors, one of which is capable of closing the open aperture by means of a lever arrangement, C, which moves a sleeve in which is fixed a pin working in a screw groove; D is an electromotor causing the sectors to rotate, and the aperture in the sectors can be opened and closed at pleasure during their revolution by means of the lever C.

Such an instrument, then, puts it in our power to equalise the shadows; and having seen what aperture of sector is required to

equalise the light passing through a portion of the plate having no deposit, the density of a deposit is measured by the ratio of the aperture required in the latter case to that of the former. Thus, if "no deposit" requires an aperture of sector of 80° to cause equality of light, and a certain deposit requires only 10°, then we know that the deposit cuts off $\frac{7}{8}$ of any light passing through it. A large number of plates exposed in the sensitometer were measured, and the results were so excellent that I went a step further. A crux in photography is to know the sensitiveness of a plate to different parts of the spectrum. This method of measurement gave a ready means of accurately doing this. A spectrum was taken on a plate in the ordinary manner, and by a comparison line-spectrum the position of the different parts of the photographed image was ascertained; but to make the matter complete it became necessary to make a scale of density on the same plate, the exposure value of the scale being known. This was effected by exposing different small parts of the unexposed portion of the plate for varying lengths of time, to a light of approximately unvarying intensity. An oil-lamp with an argand burner was found to be sufficient for the purpose. By this means, on development, we had the spectrum (in most cases that of gas-light) to be measured, a comparison spectrum of sodium and lithium, and a series of small squares of varying density, the time of exposure which gave these densities being carefully noted and recorded. This density scale was then measured in the way described, and then the spectrum was marked out in a large number of small portions, and the density of deposit of these bits carefully measured also. The image of the photographed spectrum was much enlarged on the screen, and by substituting a thick knitting-needle for the thick rod one was able to measure the average density of a very small bit of the image without any appreciable error. These measures being obtained, the relative sensitiveness of the plate to the various parts of the spectrum was readily ascertained, and could be plotted.

The scale of "density and time" was laid down on squared paper forming a curve, and then the density of deposit in the photographed spectrum was converted into its *equivalent exposure in time*, and this curve plotted. It might be objected that time of exposure and intensity of light are not interchangeable. I may say, however, that I took careful measures, and find that with the exposures given the one is convertible into the other. Here, then, we have a method of comparing the intensity of light acting on a plate solely by adding a scale as I have indicated. In the same way, by adding a scale to a photograph of the corona taken during an eclipse, a measure of the comparative intensity of light acting to form part of the image can be readily made, and can all be referred to the light of the illuminant with which the scale is made.

In the photographs of the nebulæ such as are produced by Mr. Common, if such a scale were introduced I think their value

would be very much increased, for by this artifice the relative values of the light acting at each part of the plate would be measured in a very satisfactory manner, and a record would be obtained which in time to come could be referred to to ascertain if any change in the relative brightnesses of the different parts had taken place, however small such change might be.

I give one test of the accuracy of the measurement that can be obtained by this plan. I had cut out a star of white card, (Fig. 3) in which equal distances from a fixed radius gave equal decrements of white. This star was fastened against a dead black background and rotated rapidly whilst being photographed. The photograph gave a shaded disc most dense at the centre, and nearly free from deposit at the rim. Had the black reflected no light there would have been no deposit, but as the black ground reflected 4·9 per cent. of white light this had to be taken into account. A scale was impressed on the plate as before described, and measurements of the scale and of the shaded disc

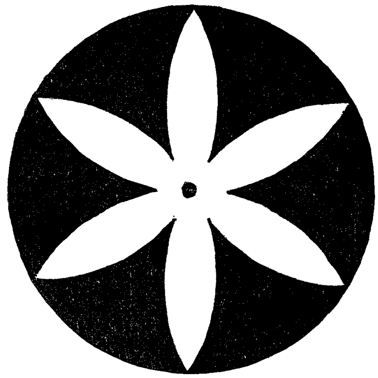


Fig. 3.

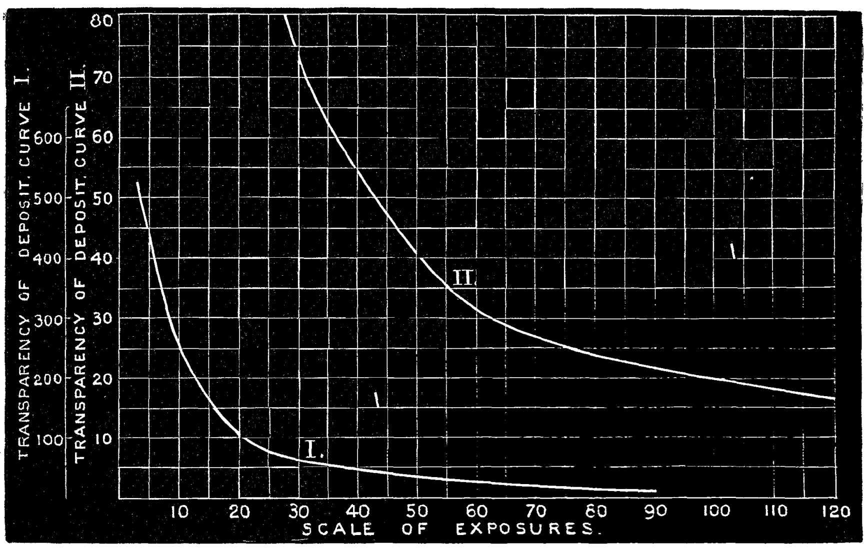
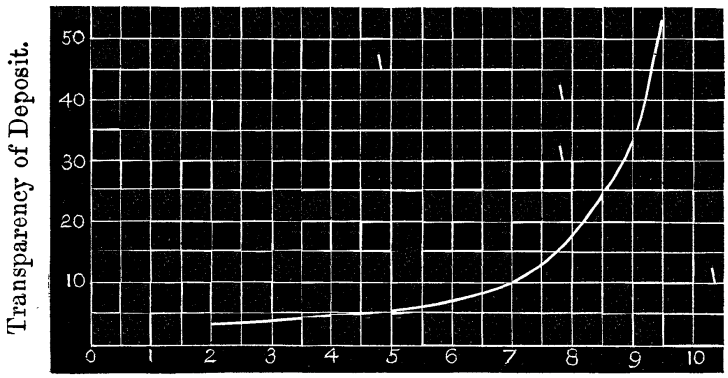


Fig. 4. Curve II. is the same as Curve I., enlarged in scale of ordinates 10 times.

made. Fig. 4 shows the density curve of the scale; Fig. 5 the density curve of the disc; whilst Fig. 6 shows the luminosity of the rotating star from calculation and from measurement. I append a table and figures to illustrate the results I obtained. It will be seen that the luminosity of the rotating star as measured from the photograph is the same as the actual luminosity, the measures lying very close to the straight line which is drawn amongst them. The small portion of light

reflected by the black surface is not sufficient to make the actual luminosity differ from a straight line on the scale to which the diagram was drawn, and may therefore be considered as prac-



Scale on Photograph.

Fig. 5.

tically a straight line. It will be noticed in Fig. 6 that the line drawn through the measured points and the line indicating the visual luminosity meet in a point, as they should

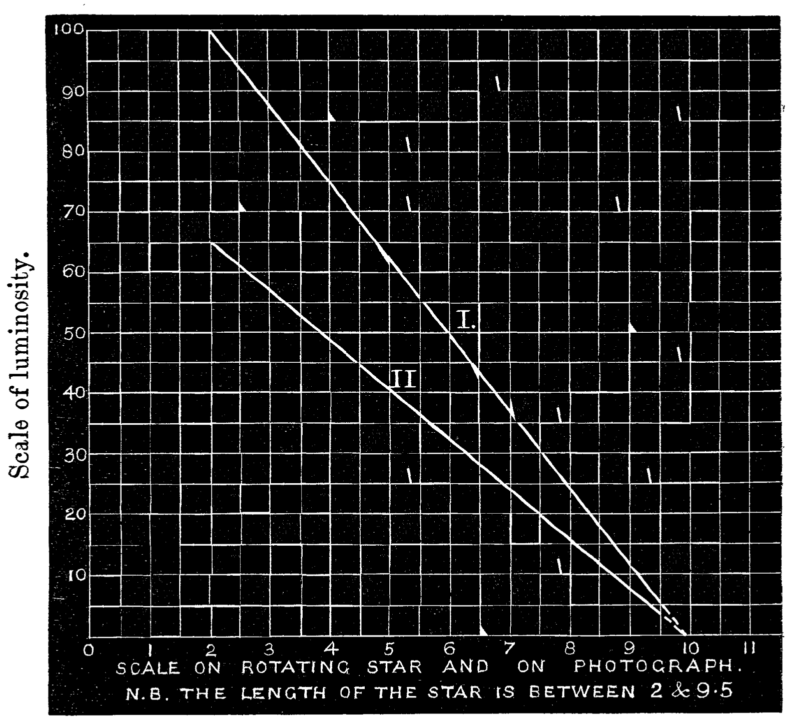


Fig. 6.

I. Luminosity of rotating star. II. Measured luminosity of photograph.

do, though beyond the limits of the star. This shows that the measured and actual luminosities are strictly proportional to one another, which of course they should be. I trust that in future work the value of attaching a density scale to each negative will be appreciated.

Distance from centre of image.	Amount of light reflected from white in %.	Amount of light reflected from black in %.	Total light reflected.	Readings of density.	Mean reading of density.	Proportion of direct light beams.	Adopted reading.	Brightness corresponding to the density from scale meas.	Brightness in %.	
inches.										
·2	100	...	100	30, 31, 31	30·6	1	30·6	67	100	
·4	100	...	100	31, 31, 30	30·6	1	30·6	67	100	
·6	86·6	·6	87·3	34, 33, 34	33·6	1	33·6	58	86·6	
·8	73·3	1·3	74·6	42, 39, 41, 40	41·0	1	41·0	50	74·6	
·9	66·6	1·6	68·2	47, 47, 47	47·0	1	47·0	45	67·2	
1·0	60·0	2·0	62·0	55, 54, 53	54·0	1	54·0	40	60·0	
1·1	53·3	2·3	55·6	60, 59, 59	54·3	1	59·3	37	55·2	
1·2	46·6	2·6	49·2	67, 66, 67	67·3	1	67·6	32·5	48·5	
1·3	40·0	3·0	43·0	78, 79, 79	78·6	1	78·6	28·0	41·8	
1·4	33·3	3·3	36·6	90, 90, 89	89·6	1	89·6	24·5	36·6	
1·6	20·0	4·0	24·0	20, 20½, 21	20·5	$\frac{1}{8}$	164·6	16·0	23·9	A second set of sectors with $\frac{1}{8}$ total circle of light rotated in front of direct light.
1·7	13·3	4·3	17·6	30, 30, 31, 31	30·5	$\frac{1}{8}$	242	11·5	17·2	
1·8	6·6	4·6	11·2	40, 41, 40	40·6	$\frac{1}{8}$	324	8·0	11·9	
1·9	...	5·0	5·0	66, 66, 67	66·3	$\frac{1}{8}$	530	3·5	5·2	

Z

Scale attached to the Photograph of the Rotating Star.

Square No.	Seconds Exposure.	Readings.	Mean Reading.	Amount of direct light on Screen.	Adopted Reading.	Remarks.
1	3	67, 67, 67	67	$\frac{1}{8}$	536	For these readings a second set of rotating sectors was placed in front of the direct light to reduce it. The direct light was thereby made only $\frac{1}{8}$ of the original light.
2	5	57, 56, 57	56·6	$\frac{1}{8}$	453	
3	10	$32\frac{1}{2}$, $33\frac{1}{2}$, 33	33·0	$\frac{1}{8}$	264	
4	15	22, 23, 22	22·6	$\frac{1}{8}$	181	
5	20	14, 16, 15, 15	15·0	$\frac{1}{8}$	120	
6	30	$8\frac{1}{2}$, $9\frac{1}{2}$, 9	9·0	$\frac{1}{8}$	72	
6	30	72, 71, 71	71·3	1		
7	45	47, 47, 47	47·0	1	47	
8	60	32, 33, $32\frac{1}{2}$	32·5	1	32·5	
9	75	26, 25, 26	25·6	1	25·6	
10	90	23, $23\frac{1}{2}$, $22\frac{1}{2}$	23·0	1	23·0	
11	120	17, $17\frac{1}{2}$, 18	17·5	1	17·5	

Note on the Law of Increase in Diameter of Star Discs on Stellar Photographs, with Duration of Exposure. By H. H. Turner, M.A., B.Sc.

In vol. xl. of the *Proc. Roy. Soc.*, p. 449, Professor Pritchard states that, according to his researches, the area of a star image varies nearly as the square root of the duration of exposure, or the diameter as the fourth root of the duration. He further remarks that Bond in 1858 considered the diameter to vary as the square root of the duration. It is therefore, perhaps, worthy of notice that, in some photographs taken at Greenwich with a Dallmeyer object-glass of 4 inches aperture and 5-foot focus, the diameter of the images seems to vary nearly as the cube root of the duration of exposure through a considerable range—a result intermediate between those of Bond and Pritchard. The following measures of the diameters of star-discs on different plates illustrate this point. The diameters are divided by the square roots, the cube roots, and the fourth roots of the durations, to exhibit the relative merits of the three hypotheses in question. It will be seen that the numbers in the cube-root column are generally nearly constant, while those in the other two decrease or increase. The numbers attached to the plates are merely those of the Greenwich series, for convenience of reference.

Plate 18. Region near *a Aquilæ.* 1887, August 31. Four exposures of 1^m, 5^m, 10^m, and 20^m, at the corners of a square.